Binary Blind Identification of Wireless Transmission Technologies for Wide-band Spectrum Monitoring

Huy Nguyen, Nam Nguyen, Guanbo Zheng, and Rong Zheng

Wireless System Research Lab
Dept. of Computer Science
University of Houston
How many different technologies are there? And what are they?
Observations and Contributions

- Technologies occupy different ranges of spectrum
- When a wireless device occupies a sub-channel, adjacent sub-channels are likely to be activated (correlated)
- **Blind identification**: no prior knowledge about the high level features wireless technologies, purely based on spectrum occupation
- **Contributions**:
  - Formulate the *blind technology identification* problem
  - Propose a *binary framework* to solve the problem
Problem Binary Formulation

• Assuming the activities of devices using different technologies are independent
• A RF transmission will cause a power surge in its associated sub-channels
• Consider an example: 3 technologies operate on 2 sub-channels

Sub-channel occupancy:

\[
\begin{array}{cccc}
1 & 1 & 0 & 0 \\
1 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{array}
\]

\[
\begin{array}{cccc}
1 & 1 & 1 & 1 \\
1 & 0 & 1 & 1 \\
\end{array}
\]

\[
(\text{unknown}) \times (\text{unknown}) = (\text{unknown})
\]
Binary Independent Component Analysis (bICA)

- **Network model**: a bipartite graph $G = g_{ij}$
  - $n$ independent binary sources $y = [y_1, y_2, \ldots, y_n]$
  - $m$ observable binary variables $x = [x_1, x_2, \ldots, x_m]$

- Observations $X$ are disjunctive mixtures of latent sources $Y$
  \[ x_i = \bigvee_{j=1}^{n} (g_{ij} \land y_j), \quad i = 1, 2, \ldots, m \quad \text{or} \quad X = G \otimes Y \]

- **Problem**: given $X$, infer the mixing matrix $G$ and the source $Y$

- Original ICA assumes continuous variables $\rightarrow$ not applicable
Proposed Procedure

1. **Spectrum occupancy inference**: remove noise and identify useful signals

2. **Sub-channel clustering**: cluster similar sub-channels to reduce inference complexity

3. **Inference and post processing**: use bICA to infer the channel occupancy matrix

4. **Technology identification**: from the center frequencies and bandwidths
Spectrum Occupancy Inference

• Separate useful signals from noise
• Mean Shift (MS) clustering method
• Noise and useful signals form different clusters
• Two-step procedure:
  – Cluster the spectrum power by applying FFT to the measurement data, determine the noise floor
  – Apply MS on 2-d data to determine all cluster means
• Clusters with means > noise floor are useful clusters
Sub-Channel Clustering

- Reducing computation complexity of bICA
- Observation: wireless technologies tend to occupy contiguous sub-channels

→ Cluster similar, contiguous sub-channels using Girvan-Newman community detection algorithm
Wireless Technology Inference

• Use bICA to infer the independent technologies occupying sub-channels

• Un-cluster the inferred result to obtain the original channel occupancy matrix ($G$)

• From $G$, determine the center frequency and bandwidth of each group

• Identify the associated wireless transmission technologies
Evaluation Setup

- **Synthetic trace**
  - 3 WiFi devices on channels 1, 6, 11 and 8 ZigBee devices on channels 11 – 18
  - Device transmission prob. in [0.05, 0.1]
  - Data noise ratio in [0, 0.1]

- **Real trace**
  - 3 WLAN devices on channels 1, 6, 11 and 4 TmoteSky ZigBee devices on channels 11, 17, 22, 26
  - 1024 points sampling for each measurement
  - Measure each 10 secs, for 500 times
Synthetic Trace Result

Matlab implementation

Channel noise = 0% – 15%

Structure error ratio: % inference error on $G$

Activity error ratio: % inference error on $Y$

Transmission prob. error: inference error on the active probability of technologies
Real Trace Result

(a) Original $G$

(b) Inferred $\hat{G}$ after structure matching

(c) Difference matrix

<table>
<thead>
<tr>
<th>Component</th>
<th>$f_c$ (GHz) Inferred</th>
<th>$f_c$ (GHz) Ground truth</th>
<th>$b$ (MHz) Inferred</th>
<th>$b$ (MHz) Ground truth</th>
<th>Technology</th>
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<td>2.4124</td>
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<td>17.766</td>
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</table>
Conclusion

• Identifying transmission technologies without prior knowledge with only binary sensing is feasible
  – Frequency domain only

• What to do next?
  – Validation using large-scale spectrum data
  – Improve accuracy and computation efficiency of the proposed algorithm
  – Incorporate cyclostationary spectrum density
THANK YOU FOR YOUR ATTENTION

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